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A review of photovoltaic systems size optimization techniques

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ABSTRACT

Based on the fact that PV systems are clean, environment friendly and secure energy sources, PV system installation has played an important role worldwide. However, the drawback of PV system is the high capital cost as compared to conventional energy sources. Currently, many research works are carried out focusing on optimization of PV systems so that the number of PV modules, capacity of storage battery, capacity of inverter, wind turbine capacity as well as diesel generator size optimally selected. In this paper, the current status of research on PV systems size optimization is reviewed taking into account standalone PV systems, hybrid PV/diesel generator systems, hybrid PV/wind systems, hybrid PV/wind/diesel generator systems as well as grid connected systems. In addition, size optimization techniques for the inverter in PV systems are reviewed. The outcome of this paper shows that the optimization of PV system is strongly depends on meteorological variables such as solar energy, ambient temperature and wind speed. Furthermore, the numerical methods are the mostly used methods. Meanwhile the artificial intelligence techniques have been employed recently to improve the process of PV system size optimization.

Contents

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1. Introduction

PV system size and performance strongly depend on metrological variables such as solar energy, wind speed and ambient temperature and therefore, to optimize a PV system, extensive studies related to the metrological variables have to be done [1]. The importance of the meteorological data in sizing PV systems lies in the fact that the PV modules output energy strongly depends on the available solar energy, ambient temperature, and the wind speed (in case of hybrid PV/wind systems).

The performance of a PV module strongly depends on the sun light conditions. Standard sunlight conditions on a clear day are assumed to be 1000 W of solar energy per square meter and it is sometimes called "one sun" or a "peak sun". Less than one sun will reduce the current output of a PV module by a proportional amount [2–4]. Furthermore, cell temperature, T_c, is an important factor in determining the performance of PV cells. The increase in cell temperature decreases PV module's voltage linearly, while increasing cell temperature increases PV module's current. The effect of cell temperature on PV modules performance depends on PV cells manufacturing. However, increasing cell temperature by 1 °C, decreases PV modules voltage by (0.085–0.123) V. On the other hand, increasing cell temperature by 1 °C increases PV modules current by (0.0026–0.0032) A [2–4]. Based on this, increasing cell temperature by 1 °C decreases PV module's power by (0.5–0.6)%. In general, most of PV modules are being tested at 25 °C, thus, a different output power is expected when PV modules are working under different climate conditions. As for wind speed, the wind turbine output power depends on the amount of wind power which hits the blades of a wind turbine. Therefore, to predict the energy produced by a wind turbine located in a specific location, a comprehensive study of the wind speed characteristic for this location must be done.

In general, the most common optimization methodology that is followed by the researchers starts by defining a specific area, and then a time series data for solar energy, ambient temperature and wind (in case of hybrid PV/wind system) is obtained. After that, the calculation of optimum tilt angle is conducted by modeling the solar energy on a tilt surface. Then based on the nature of the PV system (Standalone, grid or Hybrid) the calculation of system energy sources (PV array battery, wind turbine, diesel generator) optimum capacity is done. Finally, the size of the inverter in the PV system is calculated optimally.

Some reviews in the field of photovoltaic systems optimization have been done before. In [5] a review of hybrid renewable energy systems is conducted. The authors of this review have divided the review into three main parts. The first part of the review was dedicated for the available commercial softwares for optimizing renewable energy systems such as HOMER software. However, the author did not discuss the embedded functions used for the optimization in these softwares. In the second part, the authors reviewed some artificial intelligence techniques used for this purpose such as genetic algorithm, particle swarm optimization and simulated annealing. Finally the authors reviewed some promising methods such ant colony algorithm and artificial immune system algorithm. However, in this review the conventional methods have not been given that concern as compared to the AI methods. Moreover, some important issues in the renewable energy optimization systems such as system reliability have not been taken into consideration. In [6] issues related to hybrid PV/wind and PV/diesel systems have been reviewed. These issues include system's design, simulation, reliability, operation and optimization. In [7] optimization techniques for renewable energy systems in general have been reviewed. The renewable energies considered in this review are wind power, solar energy, hydropower, bioenergy and geothermal energy. As for solar energy systems, thermal solar energy systems were the major focus of the author while little focus has been given for photovoltaic power systems. In [8] size optimization techniques based on artificial intelligence techniques for photovoltaic power systems have been reviewed. Meanwhile conventional methods have been taken into consideration. In [9] some developments for wind and photovoltaic power systems have been reviewed. These developments include system prefeasibility analysis and unit size optimization as well as system's modelling and control for optimum energy flow. However, little focus of system size optimization has been given in this review. In [10] a review of heuristic methods for solving multi-objective optimization problems for hybrid PV systems sizing is proposed. While in [11] a review of size optimization methods for solar thermal systems is done. Based on this a comprehensive review of photovoltaic power systems (standalone, hybrid and grid connected) must be done. This review is supposed to review conventional and nonconventional optimization methods.

This paper attempts to show the current status of the conducted researches in the field of optimal sizing and installing of PV power systems. In the second section of this paper the methods for optimizing standalone PV system are reviewed and discussed. Meanwhile, optimization techniques for PV/diesel generator, PV/wind, and grid connected systems are reviewed in the third, fourth and fifth sections, respectively. On the other hand a review of size optimization techniques for the inverter in PV system lies in the sixth section. Finally, challenges to the PV system size optimization process are discussed in the seventh section.

2. Standalone PV systems size optimization

Standalone PV systems are widely used in the remote areas where there is no access to the electricity grid. These systems prove its feasibility as compared to conversional standalone power systems such as diesel generators especially for remote applications because of the difficulty in accessing the remote areas and the cost of the transportation. However, a PV system must be designed to meet the desired load demand at a defined level of security. Many sizing work for PV system can be found in the literature. Based on the reviewed work we found that there are three major PV system sizing procedures namely intuitive, numerical (simulation based) and analytical methods in addition to some individual methods.

2.1. Intuitive methods

The intuitive method is defined by [12] as a simplified calculation of the size of the system carried out without establishing any relationship between the different subsystems or taking into account the random nature of solar radiation. These methods can be based on the lowest monthly average of solar energy (worst month method) or the average annual or monthly solar energy. However the major disadvantage of this method that it may cause an over/under sizing of the designed system which results a low reliability of the system or high cost of energy produced. Some related work to this method can be found in literature. In [13] the definition of optimizing a PV system is illustrated whereas it has been defined as the process of determining the cheapest combination of PV array and battery that will meet the load requirement with an acceptable level of security over the expected life time. However, in this research the author used simple mathematical equations to calculate the size of the PV system. The required PV modules and battery capacity can be

calculated using some of formulas as below,

$$P_{PV} = \frac{E_L}{\eta_S \eta_{inv} PSH} S_f \tag{1}$$

where E_L is daily energy consumption, PSH is the peak sun hours, η_s and η_{inv} are the efficiencies of the system components and S_f is the safety factor that represents the compensation of resistive losses and PV–cell temperature losses. On the other hand, the battery capacity can be calculated by,

$$C_{Wh} = \frac{E_L \times D_{Autonomous}}{V_B DOD \eta_B} \tag{2}$$

where V_B and η_B are the voltage and efficiency of the battery block, respectively, while DOD is the permissible depth of discharge rate of a cell.

However, despite of the illustrated definition, the security of such system is not defined. Meanwhile, Khatib et al. [14] claimed that the LLP of a designed PV system using these equations cloud reach 8% which is considered very high. In [15], an optimization of PV system located in 5 sites in Iran is provided. The authors first calculated the optimum tilt angle for these sites by modeling the solar energy on a tilt surface. Then the number of the cloudy days in sites is estimated in order to know the needed capacity of the storage battery. However, the sizes of the PV array and the battery were estimated without any clear sizing method which makes the security of these systems is not trusted. In [16] a PV system design based on the intuitive method is presented for a remote area in Egypt. Meanwhile, In [17], a simple sizing of PV system is proposed for Dhaka. The calculation of the PV system size is done using the same intuitive method used in [13]. In addition, the optimum PV module/array for the same area is presented in this research. In [18] the authors used the same intuitive method in a PV expert system. This expert system aims to design and analyze PV system for regions in India. However, this system may not be comparable with current optimization softwares which use more accurate optimization techniques. In [19] the authors used the same intuitive method in order to size a building integrated PV system in India.

2.2. Numerical methods

A system simulation is used in this case. For each time period considered, usually a day or an hour, the energy balance of the system and the battery load state is calculated. These methods offer the advantage of being more accurate, and the concept of energy reliability can be applied in a quantitative manner. System reliability is defined as the load percentage satisfied by the photovoltaic system for long periods of time [13,20]. These methods allow optimizing the energy and economic cost of the system. However, these methods can be divided into two types namely stochastic and deterministic. In the stochastic methods, the author considers the uncertainty in solar radiation and load demand variation by simulating an hourly solar radiation data and load demand. Meanwhile the deterministic method is represented by using daily averaged of solar energy and load demand due to the difficulties in finding hourly solar energy available data set.

The major sizing work in the literature is based on the numerical method. In [21] LLP and related parameters are presented as a technique for sizing PV system located in Greece based on an hour-by-hour simulation. The minimum, and hence economically optimum, size of a PV system of a specified degree of reliability is determined mathematically as a function of the array orientation. In [22] the total life-cycle cost of standalone photovoltaic (SAPV) power systems is mathematically formulated. Meanwhile, an optimal sizing algorithm for the PV array and battery capacity is presented. In [23], an optimization method for the PV array area and battery storage capacity of a standalone PV system located in a Greek island is presented. The authors used monthly average meteorological data. However, the optimum system selected is the one that has the minimum life-cycle cost while it ensures a desired reliability (LLP) level. Moreover, in the life-cycle cost computations a battery-life model has been used to determine the number of battery bank replacements. In [24], a technique for sizing standalone PV systems is presented. The sizing criterion is the LLP. The technique was derived using 23 years of hourly solar energy data from 20 U.S. weather stations. These data were used to develop correlations between the variability in solar energy and average monthly horizontal solar energy. The correlations were then used to generate sizing nomograms that give the array size as a function of average horizontal solar energy and the storage capacity as a function of the LLP. A computer simulation based on a solar energy series for a PV system was performed for sizing purposes in [25]. The optimum system was selected based on the LLP and the minimum cost of energy.

In [26], a well done optimization of PV systems in Algeria is implemented by dividing the regions into four zones using the sky clearness index. The optimization of PV systems is based on loss of load probability (LLP) and a simulation program that is developed in this research. This simulation program calculates the possible sizes of a PV system at a specific LLP and load demand. After that the optimum PV system configuration is selected based on the system capital cost. However, in this research sizing curves for 12 sites in Algeria have been presented. In [27], an optimum design for PV systems in Sudan is developed based on a clear sky model for global solar prediction in Sudan. The optimization of PV panel tilt angle was done based on Jordan and Liu model for solar energy incident on a tilt surface. However, to optimize the array and storage sizes, it is assumed that the stored energy in a storage battery is equal to the difference between the load power and PV array generated power without any consideration of battery charging/discharging efficiencies. This assumption may cause serious errors in calculating the optimum PV system size. Moreover, the used PV model mathematical model is not provided but from the text it is clear that it is a simple model which does not consider some losses occurred in the system. The most two limitations of this research is that the author used a monthly solar radiation series which means that the uncertainty of the solar energy is not considered at all. Second, the authors chosen the optimum configuration based on the LLP only while the cost of the energy was not considered. This may yield an inaccurate optimization since many configurations of PV system can investigate the desired LLP.

In [28] an optimization of PV system located in Corsica is done. The optimization conducted by performing a simulation of a PV–battery system supplying a 1 kW h load. Hourly solar radiation and load demand series were used in this research. After constructing the sizing curve the optimum configuration is selected based on the cost of energy (COE) without any definition of the LLP of the selected system. In [29], an elegant optimization method for PV system is presented. A PV system mathematical model is developed to optimize its size based on a well defined solar energy data and a load demand. The developed model contains models for PV array, storage battery and charge regulator. However, the optimization considers the combined minimum cost with minimum loss of load probability taking into consideration the uncertainty of the solar energy and variation of the demanded energy by the load. The only limitation of this research is that the obtained results are limited to the assumed load demand.

Optimization of PV systems in Spain and North America has been presented in [12,20]. In these researches, the authors used

common numerical method by simulate a PV system model iteratively using daily solar radiation and a certain load demand to generate a sizing curve. Then using the result obtained by the mentioned method they established a regression model for calculating the PV array capacity. This model is represented by a linear equation in terms of mean yearly of global solar energy, minimum value of monthly global solar energy, minimum value of monthly clearness index and the variability of monthly daily solar energy. The variability of monthly daily solar energy is defined as the difference between mean yearly of global solar energy and minimum value of monthly global solar energy divided by the mean yearly of global solar energy. To validate the accuracy of the developed model, the output results of the model are compared with the method for generating sizing curves. However, there are three limitations of these researches, the first is in calculating the battery size whereas the authors supposed roughly a number of autonomy days despite the fact that the autonomy days number varies depending on the number of cloudy days during a specific time. In addition the authors neglected the battery charging/discharging efficiencies, the wire losses and all the possible losses in a PV system in order to simplify the used PV system mathematical model although that may affect the accuracy of the calculated size. Finally the authors used daily solar energy series without considering the uncertainty in the solar energy.

Optimization of PV systems in Greece has been done based on zero load rejection condition which investigates that the desired PV system is always able to supply load without any cutoffs [30]. A simulation program called “PHOTOV-III” is used to set the number of PV modules and capacity of battery based on a load demand. In the simulation, the number of the PV modules is fixed while the battery capacity value is kept changing based on load demand until zero load rejection. After that, the number of PV module is increased and the simulation is repeated. However, the authors did not define what does the zero load rejection mean and whatever, it means zero LLP or not. In [31], optimization of PV systems in Delhi is done using the loss of power probability. A defined load and daily solar energy has been used to calculate the loss of power probability. Then sizing curve is generated based on the calculated loss of power probability. The number of PV modules and battery capacity are also selected based on the minimum system cost.

In [32], an optimization of a PV system supplying a residential load demand for five sites in Turkey is presented. The optimization is done by simulating the PV system using a six years of solar energy series and a yearly load demand. After constructing the sizing curve for each site, the optimum size is selected based on the cost of energy produced by the system. In addition a life time assessment is done for the recommended PV system. The authors claimed that the payback period of such system is 6.5 years. Optimization of a PV system is done for three sites in UK by sizing curves derivation in [33]. To avoid any load interruption, the PV array size is designed based on the worst monthly average of solar energy. As for finding the minimum storage requirement, the same method used in plotting the sizing curves of the PV array is used for the battery and the minimum storage requirement is calculated for each year of the used historical data. However, the PV array size is calculated based on the worst month method which may cause an over sizing in the PV generator especially in the months that have an average solar energy higher than the worst month. Moreover the considered LLP in this research is 0.0 which is very low and affects the feasibility of the system and this appears very clear in the large sizes of the needed battery storage. In some cases the needed storage capacity reaches 6 times of the load demand while the needed PV generator size is 1.2 times the load demand. This because of the high considered reliability (0.0 LLP) meanwhile if the LLP have been increased to be 0.01 – recommended by many researchers – the size of the storage unit would have been decreased by about 50% [12,14,26,27]. A numerical method for sizing of PV systems based on the concept of loss of load probability is also developed in [34,35]. The method considers the standard deviation of loss of load probability and another two new parameters which are annual number of system failures and standard deviation of annual number of failures. The optimization of the PV array tilt angle is also done so as to maximize the collected yield.

In [36] Chance constrained programming is used for optimizing stand alone PV–battery system. The Chance constrained programming is a tool for studying mathematical models with random variables whereas this methodology is applied to deal with the uncertainly in the solar radiation. In [36] the energy status in the battery is expressed by:

$$Q_B(t+\Delta t) = Q_B(t) + (P(t) - D(t)) f(t) \Delta t \tag{3}$$

where $Q_B(t)$, $P(t)$, $D(t)$, $f(t)$ are the amount of energy supposed to be stored in the battery, generated power by the PV array, the load demand and a function represents the battery charging and discharging efficiencies, respectively. Using this equation the authors calculated the possible configuration of PV system using solar radiation data and a load demand profile. The selection of the PV system possible configuration is done based on the LLP while the optimum configuration is selected based on the cost of energy (COE). However, there are three limitations in this research first; the used PV array mathematical model is too simple whereas it does not take into account the temperature effect on PV array generated power. Second, the generated sizing curve was for different LLPs where the lowest LLP was 0.021 which consider high according to other researchers [14,26,27] who have recommended PV system design with 0.01 LLP. Finally, according to the authors the uncertainty of the solar energy is supposed to be considered in this research which means only hourly metrological series must be used. Despite of that, the authors did not provide any information about the used meteorological data (daily or hourly) and they mentioned that daily or yearly metrological series can be used.

Optimal sizing of a standalone PV system in Kuala Lumpur, Malaysia has been presented in [37]. The optimization method considers three steps in which the first step involves estimation of PV array output based on one year solar energy records. It is assumed that the output energy of a PV array is a function of peak sun shine hours, ambient temperature, and wire and dust losses. The second step is estimating the daily status of the battery storage which is done based on the previous amount of the stored energy, PV array output energy, load energy demand, battery's efficiency and inverter's efficiency. In the third step, the loss of load probability is defined and then the system cost is formulated in terms of the cost of PV array, batteries and other components. However, the system cost equation is partially derived and has to be solved graphically. Thence, the plotted graph contains two lines; one represents the loss of load probability while the other line results from the partial derivate of the system cost equation. The point of intersection of these two lines gives the optimum size of PV. However, this method has several disadvantages, such as, the sizing curve has to be constructed for each particular load, uses graphical solution rather than a precise formula to calculate the optimum PV size and determines optimal PV sizing for Kuala Lumpur region only and do not consider other regions in Malaysia.

As a general limitation of the pervious researches, there is no mention of any optimization problem for the optimized system in most of the presented methods except in [37]. In [37] the optimization problem is presented as follows,

$$\text{Minimize } C_{\text{sys}} = C_{\text{PV}}\alpha + C_{\text{batt}}\beta + C_{\text{others}} \tag{4}$$

where C_{sys} is the total costs of the systems; C_{PV} is the capacity of the solar array; C_{batt} is the capacity of the battery; C_{others} is the other total costs which is considered to be constant, including the costs of the controller with MPPT, inverter, etc. α is the unit cost of the battery ($/A h), β is the unit cost of the solar array ($/Wp). The solution of this problem can be achieved by partially differentiate is as follows,

$$\frac{\partial C_{batt}}{\partial C} = -\frac{\alpha}{\beta} \tag{5}$$

However, the searching algorithm/methodology for the optimum value or the minimum value in the generated design space by all the pervious authors still undefined. In general to search for the optimum value which is the minimum cost in most of the presented work, the first derivative method for finding the minimum point of a function – cost function – can be used such as [37]. Moreover, classical iterative methods can search for the minimum value among a data set by an iterative comparison. On the other hand, novel techniques like genetic algorithms can be employed in order to find the minimum value of the cost function.

To avoid the difficulty in calculating the optimum size by the numerical method, some of the authors employed the ANN models [38,39] a comprehensive optimization for many regions in Algeria is done. The optimization is done based on the numerical method. However, after obtaining the sizing factors of the targeted sites, an ANN model is used to predict these factors using the geographical location coordinates. The developed ANN model has two inputs namely latitude and longitude and two outputs namely C_A, C_s (the sizing factors for the PV array and the storage battery, respectively). This developed model helps in simplify the calculation of the sizing factors. The main limitations of this work are represented by the lack of the information in regards to the used metrological data (hourly or daily). Moreover, it could be understood from the tile of the article that the ANN is used in optimizing the PV system while this is not meant accurately because the ANN is used as an independent predicting tool for a specific data set. In [40] also analytical method is used to obtain a large date set of PV system optimum sizes at different LLPs then this data set is used to train an ANN to predict the optimum size of the PV array in terms of the optimum storage battery, LLP and yearly cleanses index.

In [41], the same concept presented in [38,39] is used but this time for generating the sizing curve for a specific region. Sizing curves were generated using the numerical method at different LLPs for certain sites in Algeria and then an ANN model is used to predict these sizing curve. The developed ANN model has four inputs namely latitude longitude, altitude and LLP meanwhile thirty possible CA are resulted through 30 output neurons. After predicting the C_A, the C_s is calculated in terms of C_a mathematically ($C_A = f(C_s)$) and then the predicted sizing curve is constructed. As an independent issue, the number of the neurons in the hidden layers of the developed model was optimized by a genetic algorithm in order to increase the accuracy of the developed model. However, the previous work which have been presented in [38,39] could more practical since the developed ANN model in these researches predicts the optimum C_A and C_s directly while in [41], only the sizing curve is predicted which means a searching for the optimum pair of C_A, C_s still must be done.

2.3. Analytical methods

In this case, equations describe the size of the PV system as a function of the reliability are developed. The main advantage of the this method is that the calculation of the PV system size is very simple while the disadvantage of this method is represented by the difficulty of finding the coefficients of these equation as well as that these equation are location dependant factors. In [42] a computer simulation was developed in order to predict the performance of a PV system. Then a simple fit was used to achieve a formula relating the system variables to the performance. Finally, the formulae for the optimal values of the PV array and the storage battery was constructed In [43] a method is presented for predicting the fraction of the load covered by a PV system as a function of the PV system components sizes (PV array area and battery capacity), meteorological variables and the load demand. In [44] a PV system performance and reliability are evaluated. After that, analytical expressions are obtained for the probability of the required system's storage, as well as how much auxiliary energy, on the average, would be required to cover the load in that event. In [45] analytic procedures for designing standalone PV systems based on the theory of stochastic processes were examined and recommended for designing PV system at minimum risk. In [46] the LLP is used to analyze a PV system. In this research, reliability maps are presented for each LLP considered for three Spanish locations namely Madrid, Murcia and Santander.

In [47] an optimization of PV system is presented based on a long term solar radiation series for UK. In this research the authors calculate the average of the obtained solar radiation series and divided this series in two climatic cycles. One of these climatic cycles contains the days with average solar radiation equal to or higher than the calculated overall solar radiation average while the other climatic cycle contains the days which have average solar radiation lower than the calculated overall solar radiation average. After that the necessary size of PV generator and storage battery is calculated based on all the climatic cycles in order to construct the general sizing curve. Finally the resulted sizing curve is fitted by an exponential function in order to derive a mathematical formula that can be used to calculate a PV system size directly. However, the authors in this research have supposed that all the load demand happened at the night time which rarely happens. Moreover, the author used daily load demand and solar radiation data which indicates that the uncertainties of solar radiation and the variation of the energy demanded are not considered.

In [48], the authors presented a comprehensive sizing of standalone PV system for Malaysia. a simulation is performed depending on the energy flow in a PV system presented by [36]. By this simulation, possible sizes of a PV/battery system at different LLPs for five main locations are obtained and plotted in order to establish a mathematical correlation between the capacity of the PV array capacity and the LLPs and the PV array capacity and the storage battery capacity. After calculating the coefficients for each region, the averages of these coefficients are calculated in order to establish a model for all Malaysia. However, the limitations of this research are represented by the use of daily solar energy and load demand and the difficulty in calculating the coefficients of the derived relations.

2.4. Other methods

In [49] an operation strategy for a centralized PV system located in a remote area is suggested. The suggested strategy is represented by applying a centralized storage unit for all the PV systems instead of many distributed storage units. This strategy aims to reduce the capital cost energy generated by of the PV system. A method of sizing PV system is presented.

In [50], the authors claimed that they used the ANN in modeling the PV system for sizing purposes. However, what actually have been done in this research is that the PV system components (PV array, battery, inverter, charge controller) are modeled using the well known mathematical models using five

years of meteorological data (solar radiation, ambient temperature and relative humidity). After that, the results of the modeling of the PV system components in addition to the used metrological variables were tabulated and used to train ANN predicting models. This is to say, the ANN models were used as independent predicting models not as modeling tools. As for the sizing of the PV system, an interesting idea for operating the PV system in optimum way is presented. The authors used the trained ANN models as well as intuitive sizing techniques in predicting the next day optimum configuration of the PV system. This allows controlling the size of the PV array daily using a specific controller. However, no information about the controlling methodology is mentioned in this research which makes applicability of this idea is not ensured. Moreover, the developed ANNs are only able to model PV system with components that have a commercial brands similar to the one that have been used in the training of the developed ANN model. In [51], the authors used the HOMER which considered as powerful PV system optimization tool to optimize a PV system for a rural area in southern Iraq.

2.5. Section summary

In this section, 38 research papers in the period of (1984–2012) were reviewed. About 74% of the conducted work uses a deterministic process while 26% uses a stochastic process. Despite that the stochastic process is more accurate as mentioned before because it takes into account the uncertainties in solar energy and load demand. However, the difficulty in obtaining hourly solar energy series for long time pushes the major of researchers to use the deterministic process. On the other hand, the numerical sizing method has been used in about 63% of the conducted work while the shares of the intuitive and the analytical were about 17% and 20%, respectively. This is because of the accuracy of the numerical method as compared to the intuitive method and the simplicity of the numerical method as compared to the analytical method. However, the AI techniques are employed to facilitate the use of the analytical method as shown in a part of the reviewed researches. As for the used simulation method 69% of the work is conducted by iterative simulations while 11% is done by a hybrid iterative/artificial intelligence (AI) techniques algorithm. Finally 69% of the authors used the LLP to define the security of the optimized systems while 31% proposed there optimized system without a clear security definition.

3. Hybrid PV/diesel systems size optimization

Hybrid PV/diesel systems have greater reliability for electricity production than using PV system alone because diesel engine production is independent of atmospheric conditions. The PV/diesel system will provide greater flexibility, higher efficiency and lower costs for the same energy quantity produced. In addition, PV/diesel system as compared to only diesel system provides a reduction in the operation costs and air pollutants emitted to the atmosphere [52]. Currently, some research works are carried out focusing on optimizing hybrid PV/diesel generator systems so that the number of PV modules, storage battery capacity and diesel generator capacity can be optimally selected. Hybrid PV/diesel systems can be classified into two categories; series topology and parallel topology. In the series topology, the diesel generator is connected in series with the inverter and therefore it is not able to supply the load directly while the load demand is covered by the storage battery. The disadvantages of this topology that such systems require large inverter size and low overall efficiency due to the series connection, as well as when the PV system is connected to the diesel generator it leads to a limited control of the diesel generator. However, these disadvantages can be avoided in the parallel topology whereas the diesel generator is in parallel with the inverter and can supply the load and the battery at the same time [52].

The optimization of hybrid PV/diesel systems has two main aspects; the optimization of system component and the optimization of system's operation strategy. Both aspects are being optimized based on the cost of energy produced which usually in terms of system capital cost, system running cost, system maintains cost and replacement costs. An accurate model of hybrid PV/diesel system is required in the optimization process. Such a model must be based on long term solar energy and ambient temperature series as well as a defined load demand. Two main methods of optimization can be found in the literature, iterative based and AI based methods. The iterative methods are based on an iterative simulation that calculate the possible configurations of system that fulfill the desired load demand and then these configuration are evaluated based on the cost of energy in order to select the optimum configuration. This method is perfect for the optimization work which takes into account the sizes of the system energy sources only such as PV array capacity, storage battery capacity and diesel generator capacity. On the other hand more powerful methods such as genetic algorithms (GA) can be employed to solve more complicated optimization problem which take into account the commercial brand of the components and the operation strategy. In [53], genetic algorithm is also applied for optimizing the control strategy of PV-hybrid energy system to determine the optimum configuration of the system. The control of the system is coded as a vector whose components are five decision variables for every hour of the year. However, in this optimized system, it is not clear how the optimal vector can be implemented physically in the system, and how the variation of weather would change the running of the system. In [54] the method for optimal sizing of PV/diesel system is presented. The authors in this research size the PV/battery system by an intuitive method and suggest adding a 3 kW diesel generator to be operated in the peak load time. However, in this research there is no optimization of the presented system because many other cost-effective configuration of hybrid PV/diesel system may cover the desired load demand. Moreover, the author did not define the reliability of the designed system as well as there is no information about the used meteorological data. In [52,55] dispatch strategies for the operation of a hybrid PV/diesel generator system set points are presented. Here, the determination of the optimum values of set points for the starting and stopping of the diesel generator to minimize the overall system costs is included. The optimization is done for a typical dispatch strategy whereas it predicts the long-term energy performance and the lifecycle cost of the system. In [56], optimization for hybrid PV/diesel system is presented based on the cost of energy produced taking into account a zero load rejection condition. The system is modeled based on the energy balance and the storage battery energy status. The performed simulation is done for a specific area in France using 19 years of hourly solar radiation and two topologies of load profile (low consumptions and standard). However, in this research three sizes of diesel generator is supposed while the generated sizing curves are for PV array area verses the cost of energy. Therefore, the size of the diesel generator was limited by three options which may cause an inaccurate optimization. Moreover, the proposed hybrid PV/diesel system has a series topology which has many drawbacks according to [52]. The importance of applying hybrid PV/diesel generator in Malaysia is highlighted in [57] and a techno feasibility study for applying such system in Sabah, Malaysia was carried out. The studied case considers the use of an existing 150 kW diesel generator and a PV system as an assistant system to reduce

fuel cost and carbon emission. The suggested possible configurations for the PV system are the 60 kWp PV array without storage battery, 35 kWp PV array without storage battery and a 35 kWp PV array with storage battery. Considering the system's life time cost, the option of adding a 35 kWp PV array without battery storage is recommended to be added to the existing diesel generator in which the added PV system is supposed to share about 20% of the demanded energy. However, the combined PV/diesel generator system may not be optimum since the lifetime cost can be reduced. The study in [57] determines the optimum configuration of a PV/diesel generator system by considering only the Sabah region but not for other sites in Malaysia. In [58] an analytical method for evaluating the life cycle saving of a hybrid PV/diesel system is presented. However, the authors claimed that in Brazil there are several favorable conditions to implement PV generation in the range of current electricity and oil costs.

In [59], a very good methodology for optimizing hybrid PV/diesel system is presented. The genetic algorithm is employed to optimize hybrid PV/diesel generator system. Seven variables are supposed to be optimized namely, number of PV panels, PV panel type, number of batteries, battery type, diesel generator power, inverter power and dispatch strategies. Moreover, a net present value for the proposed system is presented. A model of hybrid PV/diesel system using an hourly solar radiation data and hourly load demand is developed. This model aims to calculate hourly generated current by the PV array, demanded current by the load and the battery state of charge. The developed GA algorithm is divided into two parts, the first part aims to find the optimum configuration of the system (PV panel type and number of PV panels in parallel and battery type and number of batteries in parallel) that is needed to meet the load demand. While, the second part aims to optimize the operation strategy of each generated configuration by the first part. After that the total cost of the system is calculated in order to find the optimum configuration that investigates the minimum cost of energy. However, some point needed to be clarifying more in this research such as the way of optimizing the inverter size, how accurate the calculated hourly solar radiation data and what is the reliability level of the designed system. In [60], hybrid solar/diesel/battery systems have been modeled for the electrification of typical rural loads in remote areas of the far north province of Cameroon. Here, the Hay's anisotropic model is used to calculate hourly solar radiation received by latitude-titled and south-facing PV. The hybrid solar/diesel/battery hybrid power system comprises of a 1440 Wp solar array and a 5 kW single-phase generator operating at a load factor of 70%. For this system 136 operation hours per year of the diesel generator are required to supply a 7 kW h/day. In [61], a hybrid PV/diesel generator system for remote and rural areas is considered. It is also claimed that the combination of renewable energy sources such as PV or wind with diesel generator improves reliability and reduces the initial cost of the system. In [62] an optimization of PV/diesel generator system is presented. The authors used the presented methodology by [59] and apply it for a specific load demand in rural area in Bangladesh. In [63], a hybrid PV/diesel generator system with battery backup for a village located in Saudi Arabia is installed. Optimization of the system is done using the HOMER software and hourly solar radiation data. To determine optimal sizing of the PV/diesel generator system, several configurations of the desired system are considered using four generators of different rated powers, diesel prices, different sizes of batteries and converters. The optimized system comprises of a PV array of 2000 kWp and four generators of 1250 kW, 750 kW, 2250 kW and 250 kW operated for 3317 h/year, 4242 h/year, 2820 h/year and 3150 h/year, respectively. Based on this sizing, the cost of energy unit of diesel only and PV/diesel/battery power system with 21% solar penetration are found to be 0.190$/kW h and 0.219$/kW h, respectively for a diesel price of 0.2$/L. It was claimed that the hybrid system is more economical than the diesel system.

In [14] an optimum hybrid PV/diesel system for zero load rejection is presented. In this research, the PV array area, storage capacity and diesel generator size are supposed to be optimized based on the Malaysia weather condition and the oil cost. The objective function of the optimization problem described in [14] is in terms of a unit cost equation that describes the capital cost of a hybrid PV/diesel generator system in terms of PV module, battery, PV module support structures (ST), power electronic devices (PE), diesel generator capital cost (DGkVA), diesel generator running, system maintaining (DGrun) and system installation. Meanwhile the constrain of this optimization is the LLP of the system. A Model of hybrid PV/diesel system is developed using MATLAB and an iterative method for finding the possible configuration of the system components that fulfill the supposed load demand and the desired LLP is developed. After that, the search for the optimum configuration based on the system capital cost is done. However, the proposed method in [14], has the advantage of simplicity as compared to the method presented in [59] with an acceptable accuracy, while the disadvantages of the presented method in [14] is that there is no optimization for the operation strategies and the conducted study is done based on one climate zone namely Kuala Lumpur.

4. Hybrid PV/wind systems size optimization

Many researchers have been presented so far in order to optimally size hybrid PV/wind systems at different location around the world. These methods can be classified into three types; intuitive methods, numerical methods and Artificial intelligence (AI) methods. The intuitive methods which are usually based on simple calculation of the system size without considering the uncertainty in the solar energy and wind speed or the variation of a load demand. On the other hand, numerical method is based on a simulation programs taking into account the uncertainty nature of the weather and the load demand. Meanwhile in AI methods, algorithms such as genetic algorithms and simulated annuity are employed to solve the optimization problem

4.1. Intuitive methods

In [64], measured values of solar and wind energy for a location in UK were used to find the optimal size of a hybrid PV/wind system. The method in [64] used a simple graphical sizing curve to determine the optimum configuration of the two generators that satisfies the energy demand of users throughout the year. On the other hand, In [65], simple calculation for sizing a hybrid PV/wind system is done using real weather data for a specific region in Senegal. The calculation is done using intuitive formula and for three reliability levels. However, the main draw backs of these methods that an over/under sizing of the system is possible since the uncertainty of the weather is not considered.

4.2. Numerical methods

The numerical method is the most used method for sizing hybrid PV/wind system. The methodology of this method starts by modeling the system using mathematical relations and then using a weather data and a load demand a simulation of the system is performed. During the simulation, the amount of generated energy each time step is predicted and compared to

the load demand. Based on this the role of the battery (charging/discharging) is stated. At the end of this simulation possible configurations of the system at specific reliability level(s) are generated. Here the second part is started whereas the cost of each configuration is calculated and based on the minimum cost, the optimum system size is selected. The cost of the system usually includes the capital cost, maintains cost and replacement cost. In [66] an iterative optimization for hybrid PV/wind system was presented to determine the PV array and wind turbine sizes that can make the difference between the generated and demand powers as close as possible to zero over a period of time. By using this method, several possible combinations of PV array and wind turbine capacities were obtained. The total cost of each configuration is calculated and the combination with the lowest cost is selected to represent the optimal size. In [67], mathematical models for solar energy, wind speed, wind turbine, PV module and storage battery are used for sizing a PV/wind system. An iterative simulation is performed using these models as well as a cetin load demand to generate possible sizing curves of the system. However, the authors did not show any validation of the used metrological models as well as the recommended PV/wind size. In [68] monthly averages of solar radiation and wind speed were employed for sizing a hybrid PV/wind system. In this research an iterative method is used to size the system at a level of reliability. However the main drawback of this research is the used metrological data whereas the using of monthly averages may yield an inaccurate size.

In [69–71], optimum sizes of PV/wind systems with and without storage battery are presented for specific regions. First the optimum tilt angle of the PV array is calculated by modeling the solar energy on a tilt surface. Then a mathematical model for the PV/wind system is developed in order to predict the energy production of the systems. The optimization conducted in this research is based on LLP whereas an iterative simulation using metrological data is developed to calculate the possible configurations of the PV/wind systems that investigate the desired reliability level. After that the optimum configuration is selected based on the system cost which included the capital, running and replacement costs. However, in these researches the authors did not mentioned any optimization problem as well as the methodology of searching for the optimum size after calculating the systems costs. In [72,73], the response surface metamodel (RSM) technique is used to optimize a hybrid PV/wind system in a specific location in Turkey considering two types of load demand. According to [72] RSM consists of a group of mathematical and statistical techniques that can be used to define the relationships between the response and the independent variables. RSM defines the effect of the independent variables, alone or in combination, on the processes. In addition to analyzing the effects of the independent variables, this experimental methodology also generates a mathematical model called a metamodel. The optimization methodology in this research starts by calculating the optimum tilt angle of a PV array then develop a mathematical model for the system in order simulate using hourly metrological data and a load demand. On the other hand, In [74], the same load demands, metrological data are employed to optimize hybrid PV/wind System. In this research the same mathematical model of hybrid PV/wind system is used as well but a software tool called OptQuest is used to optimize the system. Here also the optimization methodology starts by calculating the optimum tilt angle of a PV array. In addition, an optimization problem ensures that the generated power must be higher than the load demand without any reliability limitations is described although this may yield a very large design space which makes the searching for optimum configuration more difficult. However the authors of [72–74] did not compare validity of the used methodologies (RMS and OptQuest) although such a comparison may lead to the best optimization technique.

In [75], the authors used an iterative simulation to size a hybrid PV/wind system. in this research the authors presented a new mathematical model for a wind turbine by fitting its power curve by four polynomial function. However, the accuracy of this model may degraded in case of using other wind turbine with other commercial brand. In [76], an iterative simulation is used to find out the optimum configurations of a hybrid PV/wind system that meet a desired load demand at a defined level of reliability. The simulation is conducted using a mathematical model of a hybrid PV/wind system and an hourly solar, temperature and wind records for a specific region in Algeria. The conducted iterative simulation is started by setting a wind turbine size (rotor diameter) and PV array size (array area) and then it calculates the expected energy generated by the set sizes. The generated energy is compared to the load demand and based on this comparison the battery role (charging/discharging) is stated. This simulation is repeated iteratively until reach a defined limit. After that the cost of each possible configuration is calculated in order to select the optimum one (minimum cost). However, the authors of this reach did not mention the methodology of searching for the minimum cost choice. Moreover the optimization problem and its constrains have not been defined. In [77] the authors presented an optimization of hybrid PV/wind system for Malaysia for Kuala Terengganu. The optimization conducted by an iterative simulation using a system model and long term weather data. This simulation generates possible configurations of a hybrid PV/wind system at specific load demand and five reliability revels (0.01–0.05 LLP), to avoid the limitation of using a defined load demand, a generalization of the result is done in order to make the results valid for any load demand. Moreover, monthly optimization of the PV array tilt angle as well optimization of the inverter sizing ratio (the capacity of the inverter to the capacity of the PV array) are done in this research.

However some researchers has presented partial optimization for hybrid PV/wind system by sizing the PV array, battery or the wind turbine only. In [78] a method for sizing PV/wind system is presented. The sizing methodology described in this research starts by modeling the wind and the solar radiation using statistical models, then developed a mathematical models for the PV module and wind turbine. After that the simple iterative simulation is conducted to calculate the size of the PV array in this system. However, in this research neither the wind turbine nor the storage battery sizes were optimized. Moreover, the effect of ambient temperature on the energy production of the PV array is neglected. In [79], the authors presented an optimization of PV/wind system for a specific area in England. Analytical models for the solar radiation and wind speed are developed first and then a mathematical model of the system is constructed in order to simulate the system. However, in this research no size recommendation is presented for the wind turbine whereas all the recommendations were for the PV array and battery sizes. Moreover the authors used an inaccurate model of the PV/wind system as well as they ignored the effect of ambient temperature on the performance of PV array. In [80] a methodology for sizing the PV array and the battery in hybrid PV/wind system is presented. This methodology is based on a long term metrological data, a mathematical model of a PV/Wind system as well as the LLP technique. In this research a wind turbine size is set first then an iterative method for sizing the PV array and the battery is conducted. An optimization problem in term of the cost of the PV array and the battery is developed and solved by finding the minimum function points (minimum cost) using the first derivative. In [81], a model of a wind turbine in a hybrid PV/wind system is presented. The model presented in this paper take into consideration the instantaneous variation in the wind speed. This

model provides calculation of the variable-speed wind turbine output power based on the amount of instantaneous wind speed. The traditional power curve which is used to represent the wind turbine power as a function of wind speed, was modified on the basis of simultaneous consideration of the wind speed and the wind dynamics.

4.3. Artificial intelligence methods

In this section, the use of AI methods in optimizing hybrid PV/wind system is used. However, some of the researchers use the AI method incorporated with numerical method such as what is done in [82]. In [82] the authors presented a methodology for sizing PV/wind system for a specific region. The methodology is divided into three steps. First, a mathematical model of a PV/wind system is developed and then an iterative simulation using hourly metrological data is conducted. This iterative simulation aims to generate possible configurations of a PV/Wind system for supplying a certain load demand. Finally an optimization problem in terms of the system cost and subject to a specific level of reliability is developed, while the genetic algorithm is used to solve this optimization problem. However, in this research the used PV model is in terms of the fill factor (FF), meanwhile, the FF is calculated using the maximum voltage and current of a PV module and the authors did not mentioned how they obtained these variables. Moreover, the reliability level of the optimized system is not defined and the author only mentioned that the generated energy must be higher than the load demand. On the other hand the authors of [77] used the numerical method as well the genetic algorithm (GA) algorithm to facilitate the optimization of hybrid PV/wind system. in this research the authors used the numerical method to generate the design space then the GA to search for the minimum value of the design space which is the optimum size.

In addition some researchers use the AI techniques for modeling the hybrid system whereas, In [83], an optimization of hybrid PV/wind system is conducted for an island located in Malaysia. Hourly solar radiation, wind speed and load demand is used. However, it could be understood form the title of the research that the neuro-fuzzy technique in the optimization although the neuro-fuzzy technique is not an optimization tool. Actually in this research the neuro-fuzzy technique is used to model the PV module and the wind turbine while an iterative method based on the LLP is used to optimize the system. As for the modeling using neuro-fuzzy technique, the author used the well known mathematical model of the PV module and wind turbine to generate the large data set of inputs (solar radiation, temperature and wind speed) and outputs (generated power by PV and wind turbine). This data set is used to train the neuro-fuzzy model and then the neuro-fuzzy model will be able to predict the output power based on the mentioned inputs. The main drawback of this modeling method is that the developed model is only able to predict the out power of a PV module and a wind turbine that have a commercial brand similar to the one that used in training the network.

Meanwhile, some of the researchers conducted the optimization totally by AI methods. In [84,85] a size optimization of Hybrid PV/Wind system is presented for a specific region in Hong Kong. A mathematical model of the system as well as hourly solar radiation and wind speeds records are used for this purpose. However, in this research, the optimization is totally being done by a GA. The GA is used to optimize the capacity of the PV array, wind turbine and battery as well as the optimum tilt angle of the PV array. The objective function is to minimize the cost of the system subject to a defined reliability level and specific optimum tilt angle. According to the authors, the optimization conducted has a multi objective function and consequently it is difficult to solve it by liner solutions. In [86] the authors used again the same metrological data, load demands and system model used in [72–74] to optimize hybrid PV/Wind system but using the simulated annealing (heuristic approach) this time. The objective functions in this research in minimizing the cost of the system. Meanwhile, the same optimization problem described in [74] is used but this time the problem of the large design space yielded can be solved since the authors are using a heuristic algorithm. However, the authors this time compare their former work [72] to this work and claimed that the SA yields better results.

Finally some of the important optimization issues for hybrid PV/wind system are highlighted in [87,88]. In [87], a mathematical model of a PV/Wind system is presented. This model is developed based on metrological variables for a specific area in Hong Kong. The developed model aims to analyze PV/wind systems by calculating its LLP. However, the described PV model is too complicated and needs to calculate many coefficients, as well as no methodology for calculating these coefficients is mentioned in this research. Meanwhile, in [88] the impact of using real metrological data as compared to the use of generic analytical metrological models on the sizing of PV/wind system is studied. The authors claimed that the use of metrological models yielded more accurate system sizes as compared to the use of real data according to the system's loss of load probability. The authors interpreted this as using past years metrological data resulted an inaccurate system size in the future due to the changing nature of climate.

5. Grid connected PV systems size optimization

Grid connected PV systems can be divided into two parts; building integrated PV systems (BiPV) and distribution generation PV (DGPV) systems. BiPV systems usually supply a specific load and inject the excess energy to the grid. On the other hand the GDPV systems inject the whole produced energy to the grid without feeding any local load. The grid connected systems can be consisted of PV array only as an energy source, or anther energy source can be in cooperated with the PV array such as wind turbine, diesel system or a storage unit [89]. Therefore, the methodology sizing of grid connected PV system can be the same as SAPV or hybrid PV system depending on the nature of the system. The sizing of BiPV system depends on the load demand and the amount of power needed to be injected to the grid. Meanwhile the size of DGPV system depends on the amount of power needed to be injected to the grid. However, many researches focus on the PV array size, PV array tilt angle and orientation and inverter size of gird connected systems. In [90] some parameters have been optimized for an optimum installation of a grid PV system in Spain. These parameters include shading analysis of the system location in order to avoid any external or self shading, wire losses, optimum orientation and tilt angel, inverter size. However, no size optimization for the PV array is mentioned. Moreover, the inverter size is selected by intuitive consideration. In [91] a size optimization of Grid connected system is presented. The variables which are optimized in this research are the PV generator type, inverter type and PV array tilt angle. Mathematical models for PV array, inverter and solar radiation on tilt surface are developed. using these models and real solar radiation and temperature records a possible design space is obtained using four types of PV generator, three types of inverter and seven tilt angle values Finally the configuration that investigates the maximum efficiency is selected as an optimum choice. In [92], the impact of PV array area, orientation and tilt angle, inverter sizing ratio on the feasibility of grid connected

system is highlighted. A gird connected system mathematical model as well as real whether data are used in an iterative simulation to optimally size/select the these variables.

In [93] a PV grid connected systems optimization is presented. The main objective of this research the optimal number and type of the PV modules and the DC/AC converters, the PV modules optimal tilt angle, the optimal arrangement of the PV modules within the available installation area and the optimal distribution of the PV modules among the DC/AC converters. This optimization is done using by modeling the system using real weather data by an iterative simulation.

Artificial intelligence (AI) techniques were employed also for optimizing grid connected PV systems whereas In [94] Particle swarm optimization (PSO) is used in multiobjective optimization problem for optimally design of photovoltaic grid-connected systems. The optimization's decision variables are the optimal number of the PV modules, the PV modules optimal tilt angle, the optimal placement of the PV modules within the available installation area and the optimal distribution of the PV modules among the DC/AC converters. The design optimization aims towards the maximization of both the economic and environmental benefits received by the use of grid connected system.

6. Inverter size optimization

As a fact, the rated power of a PV array must be optimally matched with inverter's rated power in order to achieve maximum PV array output power [95]. The optimal inverter sizing depends on local solar radiation and ambient temperature and inverter performance [96–98]. For instance, under low solar radiation levels, a PV array generates power at only part of its rated power and consequently the inverter operates under part load conditions with lower system efficiency. PV array efficiency is also affected adversely when an inverter's rated capacity is much lower than the PV rated capacity. On the other hand, under overloading condition, excess PV output power which is greater than the inverter rated capacity is lost [99–101]. This to say that optimal sizing of PV inverter plays a significant role in increasing PV system efficiency and feasibility.

In [102], an analytical method is presented for the calculation of optimum inverter size in grid-connected PV plants at any site in Egypt and Europe. Models for many commercial inverters efficiency curves were developed and the solar energy and ambient temperature records were used to model the PV array output which lead to optimum sizing ratio of inverters. The validity of the analytical model in [102] was tested by comparing the simulation outputs to the measured data. In [103], a simulation approach for inverter sizing based on a single inverter configuration was done for regions in Europe. In the simulation, the PV array and inverter were modeled using the solar energy and ambient temperature records. In [104], inverter sizing strategies for grid-connected photovoltaic (PV) systems are conducted for regions in Germany taking into account site-dependent peculiarities of ambient temperature, inverter operating temperature and solar irradiation distribution characteristics. In this case, 10 s irradiation values were used instead of average hourly irradiation values for sizing inverters since hourly averages hide important irradiation peaks that need to be considered. In [105], optimum PV inverter sizing ratios for grid-connected PV systems in selected European locations were determined in terms of total system output, inverter characteristics and insulation data. The maximum total system output was determined for low, medium and high efficiency inverters of different sizing ratios. In [106], PV inverter sizing is economically optimized by developing a PV module and a PV inverter model in Matlab using real solar irradiation records. The single cost categories of a PV inverter are introduced and discussed with respect to an economically optimized sizing considering reactive power supply. The results showed that the sizing of a PV inverter has to be adapted to the respective reactive power supply methods in order to keep it economically optimized.

In [107], An iterative method for optimizing inverter size in photovoltaic (PV) system for five sites in Malaysia. The sizing ratio which is the ratio of PV rated power to inverter's rated power is optimized at different load levels using different commercial inverters models. Hourly solar radiation and ambient temperature records are used to develop a Matlab model for a PV array and inverter. The model aims to estimate the inverter's efficiency in terms of PV array output power and inverter rated power.

7. Challenges for PV system size optimization

Many challenges that the optimization of PV system faces such as:

7.1. Availability of weather data

As mentioned before, the weather data such as solar energy, ambient temperature and wind speed are corner stones in the PV system optimization process. However, the availability of this data is one of the most important challenges to the optimization of PV system whereas, it is difficult to have complete weather data in a small time step such as hourly or daily records. Therefore, many modeling techniques such ANN have been employed to predict these data at sites where no available data.

7.2. Load forecasting

To obtain an optimum PV system size, a full load demand profile through a year time must be achieved. However, it is difficult to have a real load demand through a year time and therefore, the designers used to use hourly or daily averages for one day. Here also, prediction techniques such as ANN can be used to forecast the load demand through as specific time.

7.3. Models accuracy

The accuracy of the developed models for the PV systems components is very important in optimizing these systems. These models must take into account all the variables that affect the energy production such as the meteorological variables, system location and orientation as well as the inefficiencies that affect the energy conversion such as power electronic devices conversions efficiency, dust deposition and wires efficiency.

7.4. The variety of components specification

Due to the large number of the commercial brand for PV system components, the developed models for sizing PV system must take into consideration this variety. For example it is very difficult to have two identical PV modules in terms of conversion efficiency.

7.5. Simplicity and applicability of proposed methods

It is important to optimize the optimization method. In other words, the best optimization models must combine the simple concepts with the accurate results. However, this could be achieved by combining the technologies such as a part of the researches who solved the complexity if the analytical methods by incorporating AI techniques.

7.6. Generalization of the results

As mentioned before, the optimization of PV system is a location dependant process. Therefore, it is important to generalize the optimization result that have obtained based on specific location, for nearby location.

8. Conclusion

In this paper, almost 100 research papers in the period of (1982–2012) in regards to PV system size optimization were reviewed. Four types of PV system were included in this review namely standalone PV systems, PV/wind systems, PV/diesel systems and grid connected PV systems. Moreover, optimization techniques for inverter size in PV system were included. As a conclusion, the major of the used optimization methods are simulation based methods (numerical methods) which use long time series of weather data. Meanwhile the AI techniques such as genetic algorithm and ANN played an important role in improving the applicability of the optimization techniques.

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